

AP Physics C: Mechanics and Electricity and Magnetism Course Organization

Singapore American School 2021-2022

Section 1: Course Organization

The theoretical foundation for this course is the [Modeling Theory of Cognition](#), which posits that humans construct mental models to make sense of the world. These mental models are constructed of systems, structures, and representations, which allow us to understand and connect information, processes, and skills. To help students develop a [coherent system of conceptual models in physics](#), this course uses a guided-inquiry learning cycle—known as the modeling cycle—that has students do the following: 1) Perform a laboratory activity to develop a relationship between two variables, creating an initial conceptual model for a topic; 2) Discuss and practice parts of the conceptual model, developing an understanding of the conceptual model; and 3) Apply the model through more laboratory activities or projects. By the end of each modeling cycle, students have developed a coherent conceptual model for a topic; the conceptual model contains multiple representations, limits of the model, and applications of the model.

(See Sections 5 and 6 for a full list of conceptual models. See Section 7 for a conceptual model organizer.)

Although the goal is to perform a full modeling cycle for each topic, every course has constraints. For this course, the constraint is time; students have a 75-minute class on an alternating-day schedule, giving a mean of 187.5 minutes per week. This lesser amount of time has forced difficult choices about parts of the modeling cycle, so sections of the course have different foci on parts of the modeling cycle. For the Algebra-Based Electricity and Magnetism section, the focus is on the first and second parts of the modeling cycle—students will develop relationships between variables and create complete conceptual models through discussion and practice. For the Calculus-Based Mechanics section, the focus is on the second and third parts of the modeling cycle—students will create complete conceptual models through discussion and practice and apply the models through laboratory activities. For the Calculus-Based Electricity and Magnetism section, the focus returns to parts one and two of the modeling cycle. If your course has more time available, consider adding the missing parts of the models to each section.

Although this course has a lesser amount of time, students entering this course are well-prepared. All students have completed at least one previous physics course, with a high percentage coming from an [AT Computational Physics](#) course. Students must also have a co-requisite of any calculus course, though most students have completed at least one calculus course. Students at the Singapore American School are highly motivated, working diligently to perform well in their courses.

Because students have completed a physics course—with an emphasis on Mechanics—this course integrates Electricity and Magnetism with Mechanics. Thanks to the idea from [Greg Jacobs](#), this course begins with Algebra-Based Electricity and Magnetism, moves to Calculus-Based Mechanics, then returns to Calculus-Based Electricity and Magnetism. This sequence allows students to experience new material at the beginning of the course and creates space for the calculus teachers to progress through their storyline. In addition, students are less familiar with topics in Electricity and Magnetism; working through the topics twice in a single year helps deepen their understanding of the conceptual models.

The assessment system in this course is a Standards-Based Grading approach, so students will receive a semester grade from a combination of standards. Section 3 lists the topics with the percentage, learning objectives from the 2019 Course and Exam Description books, and class during which each assessment will occur. Each topic is assessed at three times, so students will have multiple opportunities to provide evidence of their learning.

General Timeline

Classes	Content	Topics
1 – 24	Algebra-Based Electricity and Magnetism	<ul style="list-style-type: none"> - Electric Field - Electric Force - Electric Potential and Electric Potential Energy - Capacitance - Resistance - Circuits – Resistor-Only - Magnetic Field - Magnetic Force
25 – 51	Calculus-Based Mechanics	<ul style="list-style-type: none"> - Linear and Angular Kinematics - Linear and Angular Momentum - Force and Torque - Energy, Work, and Power - Oscillations and Gravitation
52 – 67	Calculus-Based Electricity and Magnetism	<ul style="list-style-type: none"> - Circuits – RC, RL, and RLC - Electric Potential - Electric Flux and Gauss’ Law - Magnetic Flux and Ampère’s Law - Faraday’s and Lenz’s Laws - Maxwell’s Equations
68 – 72	Review and AP Exam	<ul style="list-style-type: none"> - Review of Mechanics and Electricity and Magnetism - AP Exams on Tuesday, 10 May <ul style="list-style-type: none"> - Mechanics: 12:00 pm - Electricity and Magnetism: 2 pm
73 – 78	Project	<ul style="list-style-type: none"> - Topic in Mechanics or Electricity and Magnetism

Table of Contents:

- Section 1: Course Organization – Page 1
- Section 2: Schedule – Page 3
- Section 3: Scoring System – Page 15
- Section 4: Comparison of Models with Book Chapters and AP Problems – Page 18
- Section 5: Models for Electricity and Magnetism – Page 21
- Section 6: Models for Mechanics – Page 28
- Section 7: Model for a Concept in AP Physics C – Page 42

Section 2: Schedule

- Students are in each class for 80 minutes on an alternating-day schedule.
- Some Class numbers are out of order due to timing of breaks in the school schedule.
- **Task** Types and *Science Practices*
 - **Activity:** Laboratory work, either hands-on or computer-based
 - *Discovery:* These activities have students collect data, graph, and perform analysis to determine a relationship between two variables. *Science Practices:* 2.A, 2.B, 2.C, 2.D, 2.E, 2.F, 3.A, 3.B, 3.C, 3.D, 4.A, 4.B, 4.C, 4.D, 4.E.
 - *Verification:* These activities have students verify a previously-studied relationship between two variables. *Science Practices:* 2.A, 2.B, 2.C, 2.D, 2.E, 2.F, 3.A, 3.B, 3.C, 3.D, 4.A, 4.B, 4.C, 4.D, 4.E.
 - *Claim-Evidence-Reasoning (CER):* These activities have students make a claim about situation, gather evidence about the claim, and provide reasoning about the veracity of the claim. *Science Practices:* 3.A, 3.B, 3.C, 3.D, 4.A, 4.B, 4.C, 4.D, 4.E, 7.A, 7.B, 7.C, 7.D, 7.E, 7.F.
 - **Discussion:** Lecture and question session on a topic.
 - **Practice:** Conceptual problems: [TIPERs](#), card sorts, and other methods; Mathematics-based problems—paper- or computer-based sources (WebAssign or AP Classroom). *Science Practices:* 1.D, 3.C, 3.D, 4.D, 5.D, 5.E, 6.A, 6.B, 6.C, 6.D.
 - **Model:** Development of a conceptual model for a topic. *Science Practices:* 1.A, 1.B, 1.C, 1.E, 3.C, 3.D, 4.A, 4.B, 4.E, 5.A.
 - **Assessment:** A written or computer-based (AP Classroom) check for understanding through conceptual questions and mathematics-based problems. *Science Practices:* 1.D, 3.C, 3.D, 4.D, 5.D, 5.E, 6.A, 6.B, 6.C, 6.D.
 - **Review:** Discussion and practice for a set of topics. *Science Practices:* 1.D, 3.C, 3.D, 4.D, 5.D, 5.E, 6.A, 6.B, 6.C, 6.D.
- **Model** is the conceptual models for a topic—see the next section of this document for the models in Electricity and Magnetism and Mechanics.
- **Learning Objectives** are from the 2019 Course and Exam Description for [Mechanics](#) and [Electricity and Magnetism](#). Each *Learning Objective* is listed for an activity, discussion, or model.
- **Science Practices** are from the 2019 Course and Exam Description for [Mechanics](#) and [Electricity and Magnetism](#). See above for groupings of *Science Practices* for each *Task*.

Class	Task	Model	Learning Objectives	Science Practices
1	- Introductions and Course Overview - Discussion: Charge; Electric fields	Electric Field and Force	ACT-1.A	
2	- Activity (Discovery): Determine the electric field created by various charge distributions. [Use Charges and Fields from PhET.] - Practice: Electric fields	Electric Field and Force	FIE-1.B FIE-1.C FIE-1.D FIE-1.E	Activity: Discovery Practice

Class	Task	Model	Learning Objectives	Science Practices
3	<ul style="list-style-type: none"> - Activities (Discovery): - Determine the relationship between charge and electric force. [Use <i>Forces and Electric Charge II</i> from Pivot Interactives.] - Determine the relationship between distance and electric force. [Use <i>Coulomb's Law Observational Experiment</i> from Pivot Interactives.] - Discussion: Electric force; Relationship between electric force and field - Practice: Electric force; Electric field 	Electric Field and Force	ACT-1.A ACT-1.B ACT-1.C ACT-1.D FIE-1.A FIE-1.F FIE-1.G	Activity: Discovery Practice
4	<ul style="list-style-type: none"> - Model: Electric field and force - Activity (Discovery): Determine the relationship between distance and electric potential. [Use Charges and Fields from PhET.] - Discussion: Electric potential 	Electric Field and Force Electric Potential and Electric Potential Energy	CNV-1.A	Model Activity: Discovery
5	<ul style="list-style-type: none"> - Assessment: Electric field and force - Discussion: Electric potential and electric potential energy - Practice: Electric potential and electric potential energy 	Electric Field and Force Electric Potential and Electric Potential Energy	CNV-1.B CNV-1.C CNV-1.D CNV-1.E CNV-1.F	Assessment Practice
6	<ul style="list-style-type: none"> - Model: Electric potential and electric potential energy - Discussion: Relationships between electric field, electric force, electric potential, and electric potential energy; Conductors - Practice: Electric potential and electric potential energy 	Electric Field and Force Electric Potential and Electric Potential Energy	ACT-2.A ACT-2.B ACT-2.C ACT-2.D ACT-2.E ACT-3.A ACT-3.B	Model Practice
7	<ul style="list-style-type: none"> - Assessment: Electric potential and electric potential energy - Activity (Discovery): Determine the electric field and electric potential in a parallel-plate capacitor. [Use Charges and Fields from PhET.] 	Electric Potential and Electric Potential Energy Capacitance	CNV-4.A	Assessment Activity: Discovery

Class	Task	Model	Learning Objectives	Science Practices
8	<ul style="list-style-type: none"> - Discussion: Capacitance - Activity (CER): Define and analyze a claim related to the impact of a dielectric on the capacitance of a parallel-plate capacitor. [Use Capacitor Lab from PhET.] - Discussion: Dielectrics - Practice: Capacitance and dielectrics 	Capacitance	CNV-4.B CNV-4.C CNV-4.F CNV-4.G CNV-4.H CNV-4.I FIE-2.A FIE-2.B FIE-2.C FIE-2.D	Activity: CER Practice
9	<ul style="list-style-type: none"> - Discussion: Combining capacitors - Practice: Combining capacitors - Model: Capacitance 	Capacitance	CNV-7.A	Practice Model
10	<ul style="list-style-type: none"> - Practice: Capacitance - Assessment: Capacitance 	Capacitance		Practice Assessment
11	<ul style="list-style-type: none"> - Practice: Electric field and force, electric potential and electric potential energy, and capacitance 	Electric Field and Force Electric Potential and Electric Potential Energy Capacitance		Practice
12	<ul style="list-style-type: none"> - Assessment: Electric field and force, electric potential and electric potential energy, and capacitance 	Electric Field and Force Electric Potential and Electric Potential Energy Capacitance		Assessment
13	<ul style="list-style-type: none"> - Activity (Discovery): Make a bulb light with one wire, one battery, and one bulb. - Discussion: Resistor-only circuits - Activity (Discovery): Determine the relationship between electric potential and current. [Use Circuit Construction Kit: DC from PhET.] 	Resistance Circuits	FIE-3.A FIE-3.B	Activity: Discovery

Class	Task	Model	Learning Objectives	Science Practices
14	<ul style="list-style-type: none"> - Discussion: Resistor-only circuits and resistance - Activity/Practice (Verification): Calculate and verify electric potential, current, and resistance of resistor-only circuits. [Use Circuit Construction Kit from PhET.] 	Resistance Circuits	FIE-3.C FIE-3.D FIE-3.E FIE-3.F CNV-5.A CNV-5.B CNV-6.A CNV-6.B CNV-6.C CNV-6.D CNV-6.E	Activity: Verification Practice
15	<ul style="list-style-type: none"> - Activity (CER): Determine the optimum load resistance to generate maximum power from photovoltaic cells. [Use <i>Optimizing Power Generation from Photovoltaic Cells</i> from Pivot Interactives.] - Model: Resistor-only circuits and resistance 	Circuits		Activity: CER Model
16	<ul style="list-style-type: none"> - Practice: Resistor-only circuits and resistance - Assessment: Resistor-only circuits and resistance 	Resistance Circuits		Practice Assessment
17	<ul style="list-style-type: none"> - Activity (Discovery): Determine the magnetic field generated by a current-carrying wire. - Discussion: Magnetic field 	Magnetic Field	FIE-5.A FIE-5.B	Activity: Discovery
18	<ul style="list-style-type: none"> - Discussion: Magnetic field - Practice: Magnetic field - Model: Magnetic field 	Magnetic Field		Model Practice
19	<ul style="list-style-type: none"> - Activity (Discovery): Determine force on a current-carrying wire. 	Magnetic Field Magnetic Force	FIE-4.A	Activity: Discovery

Class	Task	Model	Learning Objectives	Science Practices
20	<ul style="list-style-type: none"> - Discussion: Magnetic force - Model: Magnetic force - Practice: Magnetic force 	Magnetic Force	FIE-4.B FIE-4.C FIE-5.C CHG-1.A CHG-1.B CHG-1.C CHG-1.D CHG-1.E	Practice Model
21	<ul style="list-style-type: none"> - Activity (Discovery): Determine the properties of a solenoid. - Practice: Magnetic field and force 	Magnetic Field Magnetic Force		Activity: Discovery Practice
22	<ul style="list-style-type: none"> - Practice: Magnetic field and force - Assessment: Magnetic field and force 	Magnetic Field Magnetic Force		Practice Assessment
23	<ul style="list-style-type: none"> - Review: Algebra-based electricity and magnetism 	All in E/M		Review
24	<ul style="list-style-type: none"> - Assessment: Algebra-based electricity and magnetism 	All in E/M		Assessment
25	<ul style="list-style-type: none"> - Activity (Verification): Create a method for landing a marble in a moving buggy. - Discussion: Linear kinematics and projectile motion - Practice: Linear kinematics and projectile motion 	Constant Linear Velocity Uniform Linear Acceleration 2-D Motion	CHA-1.A CHA-1.B CHA-1.C CHA-2.A CHA-2.B CHA-2.C CHA-2.D	Activity: Verification Practice
26	<ul style="list-style-type: none"> - Activity (Discovery): Using a flying pig, determine the relationship between angle and time. - Discussion: Angular kinematics - Practice: Angular kinematics 	Constant Angular Velocity Uniform Angular Acceleration	INT-2.A CHA-4.A CHA-4.B	Activity: Discovery Practice

Class	Task	Model	Learning Objectives	Science Practices
27	<ul style="list-style-type: none"> - Model: Linear and angular kinematics - Practice: Linear and angular kinematics - Assessment: Linear and angular kinematics 	Constant Linear Velocity Uniform Linear Acceleration 2-D Motion Constant Angular Velocity Uniform Angular Acceleration		Model Practice Assessment
28	<ul style="list-style-type: none"> - Activity (Verification): For two types of collisions, determine if linear momentum is conserved. - Discussion: Linear momentum - Practice: Linear momentum - Model: Linear momentum 	Linear Momentum	INT-5.A INT-5.C CON-4.A CON-4.B CON-4.C CON-4.E CON-4.F	Activity: Verification Practice Model
29	<ul style="list-style-type: none"> - Activity (Discovery): Determine the balance point for various configurations of mass. - Discussion: Center of mass, moment of inertia, and angular momentum - Practice: Center of mass, moment of inertia, and angular momentum 	Angular Momentum	CHA-3.A CHA-3.B CHA-3.C CON-4.D CON-5.A CON-5.B INT-6.C INT-6.D INT-6.E	Activity: Discovery Practice
30	<ul style="list-style-type: none"> - Activity (Verification): During a collision, determine if angular momentum is conserved. - Model: Linear and angular momentum 	Angular Momentum	CON-5.C CON-5.D	Activity: Verification Model
31	<ul style="list-style-type: none"> - Practice: Linear and angular momentum - Assessment: Linear and angular momentum 	Linear Momentum Angular Momentum		Practice Assessment

Class	Task	Model	Learning Objectives	Science Practices
32	<ul style="list-style-type: none"> - Discussion: Balanced and unbalanced force - Practice: Balanced and unbalanced force 	Balanced Force Unbalanced Force	INT-1.A INT-1.B INT-1.C INT-1.D INT-1.E INT-1.F INT-1.G INT-3.A INT-3.B INT-5.B INT-5.D INT-5.E	Practice
33	<ul style="list-style-type: none"> - Activity (Verification): Using a flying pig, determine the angle the string makes with the ceiling by two different methods; goal is less than 2% difference. - Discussion: Centripetal force - Practice: Centripetal force 	Unbalanced Force	INT-2.A INT-2.B INT-2.C INT-2.D INT-2.E	Activity: Verification Practice
34	<ul style="list-style-type: none"> - Practice: Balanced and unbalanced force - Assessment: Balanced and unbalanced force 	Balanced Force Unbalanced Force		Practice Assessment
35	- Review: Calculus-based mechanics in the first semester	All in Mechanics		Review
36	- Assessment: Calculus-based mechanics in the first semester	All in Mechanics		Assessment
37	- Review: Semester exam	All in semester		Review
38	- Semester Exam	All in semester		Assessment
39	<ul style="list-style-type: none"> - Activity (Discovery): Determine the relationship between torque and moment of inertia. - Discussion: Balanced and unbalanced torque - Practice: Balanced and unbalanced torque 	Balanced Torque Unbalanced Torque	INT-6.A INT-6.B INT-7.A INT-7.B INT-7.C	Activity: Discovery Practice

Class	Task	Model	Learning Objectives	Science Practices
40	- Model: Balanced and unbalanced torque - Practice: Balanced and unbalanced torque	Balanced Torque Unbalanced Torque		Model Practice
41	- Practice: Balanced and unbalanced torque - Assessment: Balanced and unbalanced torque	Balanced Torque Unbalanced Torque		Practice Assessment
42	- Discussion: Energy - Practice: Energy	Energy, Work, Power	CON-1.D CON-1.E CON-2.A CON-2.C INT-7.E	Practice
43	- Model: Energy, work, and power - Discussion: Energy, work, and power - Practice: Energy, work, and power	Energy, Work, Power	CON-1.A CON-1.B CON-1.C CON-1.F CON-2.B CON-2.D CON-3.A CON-4.B INT-4.A INT-4.B INT-4.C INT-7.D	Model Practice
44	- Activity (Verification): Determine the theoretical and actual landing locations for two objects rolling down an incline.	Energy, Work, Power	CON-1.E CON-2.A CON-2.B	Activity: Verification
45	- Practice: Energy, work, and power - Assessment: Energy, work, and power	Energy, Work, Power		Assessment

Class	Task	Model	Learning Objectives	Science Practices
46	<ul style="list-style-type: none"> - Activity (Discovery): Determine the relationship between circular motion and simple harmonic motion. [Use <i>vISLE 5.1: Exploring the Kinematics and Dynamics of Simple Harmonic Motion</i> from Pivot Interactives.] - Discussion: Oscillations 	Oscillations	INT-8.A INT-8.B INT-8.C INT-8.D INT-8.E INT-8.F INT-8.G INT-8.H INT-8.I INT-8.J INT-8.K	Activity: Discovery
47	<ul style="list-style-type: none"> - Activity (Verification): Given constraints, calculate and verify the intersection point of a pendulum and block on a buggy. 	Oscillations		Activity: Verification Practice
48	<ul style="list-style-type: none"> - Model: Oscillations - Discussion: Gravitation - Practice: Gravitation 	Oscillations Gravitation	FLD-1.A FLD-1.B FLD-1.C CON-6.A CON-6.B CON-6.C CON-6.D CON-6.E CON-6.F CON-6.G CON-6.H CON-6.I	Model Practice
49	<ul style="list-style-type: none"> - Practice: Oscillations and gravitation - Assessment: Oscillations and gravitation 	Oscillations Gravitation		Practice Assessment
50	<ul style="list-style-type: none"> - Review: Calculus-based mechanics in the second semester 	All in Mechanics		Review
51	<ul style="list-style-type: none"> - Assessment: Calculus-based mechanics in the second semester 	All in Mechanics		Assessment
52	<ul style="list-style-type: none"> - Activity (Discovery): Determine the time constant for combinations of resistors and capacitors. - Discussion: RC circuits - Practice: RC circuits 	Circuits	CNV-7.B CNV-7.C CNV-7.D CNV-7.F CNV-7.G	Activity: Discovery Practice

Class	Task	Model	Learning Objectives	Science Practices
53	<ul style="list-style-type: none"> - Discussion: RL and LC circuits - Practice: RL and LC circuits 	Circuits Electrostatics	CNV-2.A CNV-10.A CNV-10.B CNV-10.C CNV-10.D CNV-10.E	Practice
54	<ul style="list-style-type: none"> - Discussion: Electric flux and Gauss' Law - Practice: Gauss' Law 	Electrostatics	CNV-2.B CNV-2.C CNV-2.D CNV-2.E CNV-2.F CNV-4.E	Practice
55	<ul style="list-style-type: none"> - Practice: RC, RL, and LC circuits; Electrostatics 	Circuits Electrostatics	CNV-1.G CNV-3.A CNV-3.B CNV-3.C	Practice
56	<ul style="list-style-type: none"> - Assessment: Torque, Circuits, and Electrostatics 	Torque Circuits Electrostatics		Assessment
57	<ul style="list-style-type: none"> - Activity (Discovery): Determine the magnetic flux density inside a levitated disk magnet. [Use <i>Magnet Accelerated by Electric Current</i> from Pivot Interactives.] 	Electromagnetism	FIE-4.A INT-6.A	Activity: Discovery
58	<ul style="list-style-type: none"> - Discussion: Magnetic flux and Ampère's Law - Practice: Magnetic flux and Ampère's Law 	Electromagnetism	CNV-8.A CNV-8.B CNV-8.C CNV-8.D CNV-8.E CNV-9.A	Practice

Class	Task	Model	Learning Objectives	Science Practices
59	<ul style="list-style-type: none"> - Activity (Discovery): Determine the magnetic field in a gap using a coil moving through the gap. [Use <i>Electromagnetic Induction</i> from Pivot Interactives.] - Discussion: Faraday’s and Lenz’s Laws - Practice: Faraday’s and Lenz’s Laws 	Electromagnetism	FIE-6.A	Activity: Discovery Practice
60	<ul style="list-style-type: none"> - Discussion: Faraday’s and Lenz’s Laws - Practice: Faraday’s and Lenz’s Laws 	Electromagnetism	ACT-4.A ACT-4.B	Practice
61	<ul style="list-style-type: none"> - Activity (CER): Develop and analyze a claim related to magnets falling through a solenoid. 	Electromagnetism		Activity: CER
62	<ul style="list-style-type: none"> - Practice: Faraday’s and Lenz’s Laws - Discussion: Maxwell’s equations 	Electromagnetism	FIE-7.A	Practice
63	<ul style="list-style-type: none"> - Practice: Electromagnetism 	Electromagnetism		Practice
64	<ul style="list-style-type: none"> - Assessment: Energy, work, and power; Oscillations and gravitation; Electromagnetism 	Energy, Work, Power Oscillations Gravitation Electromagnetism		Assessment
65	<ul style="list-style-type: none"> - Review: Calculus-based electricity and magnetism 	All in E/M		Review
66	<ul style="list-style-type: none"> - Review: AP Exams 	All		Review
67	<ul style="list-style-type: none"> - Assessment: Calculus-based electricity and magnetism 	All in E/M		Assessment
68	<ul style="list-style-type: none"> - Review: AP Exams 	All		Review
69	<ul style="list-style-type: none"> - Assessment: Calculus-based electricity and magnetism 	All in E/M		Assessment
70	<ul style="list-style-type: none"> - Review: AP Exams 	All		Review
71	<ul style="list-style-type: none"> - Review: AP Exams 	All		Review
72	<ul style="list-style-type: none"> - AP Exams: Mechanics and Electricity and Magnetism 	All	All	

Class	Task	Model	Learning Objectives	Science Practices
73	- Project on a topic in Mechanics or Electricity and Magnetism			
74	- Project on a topic in Mechanics or Electricity and Magnetism			
75	- Project on a topic in Mechanics or Electricity and Magnetism			
76	- Project on a topic in Mechanics or Electricity and Magnetism			
77	- Project on a topic in Mechanics or Electricity and Magnetism			
78	- Project on a topic in Mechanics or Electricity and Magnetism			

Section 3: Scoring System

Semester 1					
Topic	Semester Grade (%)	Learning Objectives	Assessment – Class Number		
			1 st	2 nd	3 rd
Electric Field and Force	11	FIE-1.B, FIE-1.C, FIE-1.D, FIE-1.E, ACT-1.A, ACT-1.B, ACT-1.C, ACT-1.D, FIE-1.A, FIE-1.F, FIE-1.G	5	12	24
Electric Potential and Electric Potential Energy	11	CNV-1.A, CNV-1.B, CNV-1.C, CNV-1.D, CNV-1.E, CNV-1.F, ACT-2.A, ACT-2.B, ACT-2.C, ACT-2.D, ACT-2.E, ACT-3.A, ACT-3.B	7	12	24
Capacitance	11	CNV-4.A, CNV-4.B, CNV-4.C, CNV-4.F, CNV-4.G, CNV-4.H, CNV-4.I, FIE-2.A, FIE-2.B, FIE-2.C, FIE-2.D, CNV-7.A	10	12	24
Circuits and Resistance	11	FIE-3.A, FIE-3.B, FIE-3.C, FIE-3.D, FIE-3.E, FIE-3.F, CNV-5.A, CNV-5.B, CNV-6.A, CNV-6.B, CNV-6.C, CNV-6.D, CNV-6.E, CNV-6.F, CNV-6.G	16	24	Exam
Magnetic Field and Force	12	FIE-5.A, FIE-5.B, FIE-4.A, FIE-4.B, FIE-4.C, FIE-5.C, CHG-1.A, CHG-1.B, CHG-1.C, CHG-1.D, CHG-1.E	22	24	Exam
Linear and Angular Kinematics	11	CHA-1.A, CHA-1.B, CHA-1.C, CHA-2.A, CHA-2.B, CHA-2.C, CHA-2.D, INT-2.A, CHA-4.A, CHA-4.B	27	36	Exam
Linear and Angular Momentum	11	INT-5.A, INT-5.C, CON-4.A, CON-4.B, CON-4.C, CON-4.E, CON-4.F, CHA-3.A, CHA-3.B, CHA-3.C, CON-4.D, CON-5.A, CON-5.B, INT-6.C, INT-6.D, INT-6.E, CON-5.C, CON-5.D	31	36	Exam

Forces	12	INT-1.A, INT-1.B, INT-1.C, INT-1.D, INT-1.E, INT-1.F, INT-1.G, INT-3.A, INT-3.B, INT-5.B, INT-5.D, INT-5.E, INT-2.A, INT-2.B, INT-2.C, INT-2.D, INT-2.E, INT-1.H, INT-1.I, INT-1.J	34	36	Exam
Laboratory Skills	10		19	28	30

Semester 2					
Topic	Semester Grade (%)	Learning Objectives	Assessment – Class Number		
			1st	2nd	3rd
Torque	12	INT-6.A, INT-6.B, INT-7.A, INT-7.B, INT-7.C	41	51	56
Energy, Work, Power	14	CON-1.D, CON-1.E, CON-2.A, CON-2.C, INT-7.E, CON-1.A, CON-1.B, CON-1.C, CON-1.F, CON-2.B, CON-2.D, CON-3.A, CON-4.B, INT-4.A, INT-4.B, INT-4.C, INT-7.D	45	51	64
Oscillations and Gravitation	12	INT-8.K, INT-8.A, INT-8.B, INT-8.C, INT-8.D, INT-8.E, INT-8.F, INT-8.G, INT-8.H, INT-8.I, INT-8.J, INT-8.K, FLD-1.A, FLD-1.B, FLD-1.C, CON-6.A, CON-6.B, CON-6.C, CON-6.D, CON-6.E, CON-6.F, CON-6.G, CON-6.H, CON-6.I	49	51	64
Circuits	12	CNV-7.B, CNV-7.C, CNV-7.D, CNV-7.F, CNV-7.G, CNV-10.A, CNV-10.B, CNV-10.C, CNV-10.D, CNV-10.E	56	67	69
Electrostatics	12	CNV-2.A, CNV-2.B, CNV-2.C, CNV-2.D, CNV-2.E, CNV-2.F, CNV-4.E, CNV-1.G, CNV-3.A, CNV-3.B, CNV-3.C	56	67	69
Electromagnetism	14	CNV-8.A, CNV-8.B, CNV-8.C, CNV-8.D, CNV-8.E, CNV-9.A, FIE-6.A, ACT-4.A, ACT-4.B, FIE-7.A	64	67	69
Laboratory Skills	12		44	47	61
Project	12		78		

Section 4: Comparison of Models with Book Chapters and AP Problems

Books

- “HRW” is *Fundamentals of Physics* (8th Edition) by Halliday, Resnick, and Walker
- “OpenStax (Vol. 1)” is [University Physics, Volume 1](#) by OpenStax
- “OpenStax (Vol. 2)” is [University Physics, Volume 2](#) by OpenStax

AP Problems are released FRQs from the College Board. Although problems have parts from different models, the listed problem is the model with the most parts in the problem.

- [Mechanics](#)
- [Electricity and Magnetism](#)

Models	Book Chapters	AP Problems
<p>Electric Field and Force</p> <p>Electric Potential and Electric Potential Energy</p>	<p>HRW</p> <ul style="list-style-type: none"> - Ch. 21: 21.1 – 21.6 - Ch. 22: 22.1 – 22.8 - Ch. 24: 24.1 – 24.7, 24.8, 24.9, 24.10 <p>OpenStax (Vol. 2)</p> <ul style="list-style-type: none"> - Ch. 5: 5.1 – 5.6 - Ch. 7: 7.1 – 7.6 	<ul style="list-style-type: none"> - 2010: 1 - 2016: 1
<p>Circuits</p> <p>Capacitance</p> <p>Resistance</p>	<p>HRW</p> <ul style="list-style-type: none"> - Ch. 25: 25.1 – 25.7 - Ch. 26: 26.1 – 26.7 - Ch. 27: 27.1 – 27.9 <p>OpenStax (Vol. 2)</p> <ul style="list-style-type: none"> - Ch. 8: 8.1 – 8.5 - Ch. 9: 9.1 – 9.5 - Ch. 10: 10.1 – 10.6 - Ch. 14: 14.4 	<ul style="list-style-type: none"> - 2007: 1 - 2008: 2 - 2009: 2 - 2010: 2 - 2011: 2 - 2012: 2 - 2013: 2 - 2014: 1 - 2015: 2 - 2016: 2 - 2017: 2 - 2018: 2 - 2019 (1): 2 - 2019 (2): 1
<p>Magnetic Field</p> <p>Magnetic Force</p>	<p>HRW</p> <ul style="list-style-type: none"> - Ch. 28: 28.1 – 28.9 - Ch. 29: 29.1 – 29.3 <p>OpenStax (Vol. 2)</p> <ul style="list-style-type: none"> - Ch. 11: 11.1 – 11.7 - Ch. 12: 12.1 – 12.4 	<ul style="list-style-type: none"> - 2007: 3 - 2008: 3 - 2019 (2): 3

Models	Book Chapters	AP Problems
Electromagnetism	HRW - Ch. 23: 23.1 – 23.8 - Ch. 29: 29.4, 29.5 - Ch. 30: 30.1 – 30.10 - Ch. 32: 32.1 – 32.5 OpenStax (Vol. 2) - Ch. 6: 6.1 – 6.4 - Ch. 12: 12.5 – 12.6 - Ch. 13: 13.1 – 13.7 - Ch. 14: 14.1 – 14.3 - Ch. 16: 16.1	- 2007: 2 - 2008: 1 - 2009: 1, 3 - 2010: 3 - 2011: 1, 3 - 2012: 1, 3 - 2013: 1, 3 - 2014: 2, 3 - 2015: 1, 3 - 2016: 3 - 2017: 1, 3 - 2018: 1, 3 - 2019 (1): 1, 3 - 2019 (2): 2
Constant Linear Velocity Constant Angular Velocity Uniform Linear Acceleration Uniform Angular Acceleration 2-D Motion	HRW - Ch. 1: 1.1 – 1.7 - Ch. 2: 2.1 – 2.9 - Ch. 4: 4.1 – 4.9 - Ch. 10: 10.1 – 10.5 OpenStax (Vol. 1) - Ch. 1: 1.1 – 1.7 - Ch. 3: 3.1 – 3.6 - Ch. 4: 4.1 – 4.5 - Ch. 10: 10.1 – 10.3	- 2007: 1 - 2013: 1 - 2015: 1 - 2018: 1
Linear Momentum Angular Momentum	HRW - Ch. 3: 3.1 – 3.8 - Ch. 9: 9.1, 9.2, 9.4, 9.7, 9.9, 9.10, 9.11 - Ch. 10: 10.7 - Ch. 11: 11.7, 11.9 – 11.11 OpenStax (Vol. 1) - Ch. 2: 2.1 – 2.4 - Ch. 9: 9.1, 9.3 – 9.6 - Ch. 10: 10.5 - Ch. 11: 11.2, 11.3 (no torque or energy)	- 2014: 3 - 2016: 3 - 2018: 2 - 2019 (1): 2

Models	Book Chapters	AP Problems
Balanced Force Unbalanced Force	HRW - Ch. 5: 5.1 – 5.9 - Ch. 6: 6.1 – 6.5 - Ch. 9: 9.3, 9.5, 9.6, 9.12 - Ch. 10: 10.8, 10.9 - Ch. 11: 11.1, 11.2, 11.4-11.6, 11.8 - Ch 12: 12.1 – 12.6 OpenStax (Vol. 1) - Ch. 5: 5.1 – 5.7 - Ch. 6: 6.1 – 6.4 - Ch. 9: 9.2, 9.7 - Ch. 10: 10.6, 10.7 - Ch. 11: 11.1 - Ch. 12: 12.1, 12.2	- 2007: 1 - 2008: 1 - 2009: 3 - 2010: 1, 3 - 2011: 1, 2 - 2012: 3 - 2013: 2 - 2016: 1 - 2017: 1 - 2018: 3 - 2019 (1): 1 - 2019 (2): 1
Balanced Torque Unbalanced Torque	HRW - Ch. 10: 10.8, 10.9 - Ch. 11: 11.6, 11.8 OpenStax (Vol. 1) - Ch. 10: 10.6, 10.7 - Ch. 11: 11.1 - Ch. 12: 12.1, 12.2	- 2008: 2 - 2013: 3
Energy Work Power	HRW - Ch. 7: 7.1 – 7.9 - Ch. 8: 8.1 – 8.8 - Ch. 9: 9.8 - Ch. 10: 10.6, 10.10 - Ch. 11: 11.3 OpenStax (Vol. 1) - Ch. 7: 7.1 – 7.4 - Ch. 8: 8.1 – 8.5 - Ch. 10: 10.4, 10.8	- 2007: 3 - 2008: 3 - 2009: 1 - 2010: 2 - 2012: 2 - 2013: 3 - 2014: 1, 2 - 2015: 3 - 2017: 2, 3 - 2018: 2 - 2019 (1): 3 - 2019 (2): 2, 3
Oscillations Gravitation	HRW - Ch. 13: 13.1 – 13.8 - Ch. 15: 15.1 – 15.7 OpenStax (Vol. 1) - Ch. 13: 13.1 – 13.5 - Ch. 15: 15.1 – 15.4	- 2007: 2 - 2008: 3 - 2009: 2 - 2011: 3 - 2012: 1 - 2015: 2

Section 5: Models for Electricity and Magnetism

Notes:

- I have listed at most two applications; however, models have many more than two applications.
- These models were presented twice—once at during the algebra-based electricity and magnetism section and another during the calculus-based electricity and magnetism section. These models are the calculus version.

1. Model for Electric Field and Force

a. Written Statements – Explanations and Predictions

- All matter is composed of charged particles, with varying charge mobility in different materials.
- For two positively charged objects, the electric force vectors point away from the objects; for one negatively charged object and one positively charged object, the electric force vectors point towards the objects.
- Neutral matter may be polarized, creating a localized electric field at the location of the space of non-zero net charge.
- Electric force is dependent on charges and distance.
- For a positive test charge, the electric field vector points in the same direction as the electric force vector.
- The permittivity of free space (ϵ_0) is included as a constant in the electric force and electric field equations.
- Electric flux is the quantitative measure of the amount and direction of electric field over an entire surface.
- Gaussian surfaces can be used to determine values associated with electric fields and charge distributions.

b. Equations

- $|\vec{F}_e| = \frac{1}{4\pi\epsilon_0} \left| \frac{q_1 q_2}{r^2} \right|$
- $\vec{E} = \frac{\vec{F}_e}{q}$
- $\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q_1}{|\vec{r}|^2} \hat{r}$
- $\Phi_E = \oint \vec{E} \cdot d\vec{A} = \frac{Q}{\epsilon_0}$

c. Graphs

- Electric field versus charge
- Electric field versus distance

d. Diagrams

- Free-body diagram
- Force diagram
- System interaction diagram
- Electric field diagram
- Electric flux diagram, with Gaussian surface

e. Applications

- Spark plug
- Taser

f. Limits

- Moving charges

2. Model for Electric Potential and Electric Potential Energy

- a. Written Statements – Explanations and Predictions
 - i. Electric potential is a property of location, not a material.
 - ii. Motion perpendicular to electric field lines does not have a change in energy; motion non-perpendicular to electric field lines does have a change in energy.
 - iii. Electric potential energy is difficult to measure, so scientists use the definition of electric potential.
 - iv. The electric field for a charge distribution is perpendicular to the equipotential and points from a higher equipotential to a lower equipotential.
- b. Equations
 - i. $E_x = -\frac{dV}{dx}$
 - ii. $\Delta V = -\int \vec{E} \cdot d\vec{r}$
 - iii. $V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$
 - iv. $U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$
- c. Graphs
 - i. Electric field versus position
 - ii. Electric potential versus charge
 - iii. Electric potential versus distance
- d. Diagrams
 - i. Equipotentials for point charges
 - ii. Equipotentials for continuous charge distributions
- e. Applications
 - i. Circuits
 - ii. Cathode-ray tube
- f. Limits
 - i. Moving charges

3. Model for Capacitance

a. Written Statements – Explanations and Predictions

- i. Creating an uneven distribution of charge produces an electric field and electric potential difference between two locations.
- ii. Capacitors store energy as an electric field.
- iii. Capacitance adds when capacitors are connected in parallel; capacitance reduces when capacitors are connected in series.
- iv. Capacitance is directly proportional to the dielectric constant and surface area; capacitance is inversely proportional to plate separation distance.

b. Equations

- i. $C = \frac{\kappa\epsilon_0 A}{d}$
- ii. $\Delta V = \frac{Q}{C}$
- iii. $C_p = \sum_i C_i$
- iv. $\frac{1}{C_s} = \sum_i \frac{1}{C_i}$
- v. $U_C = \frac{1}{2} Q \Delta V = \frac{1}{2} C (\Delta V)^2$

c. Graphs

- i. Capacitance versus plate area
- ii. Capacitance versus plate separation distance

d. Diagrams

- i. Surface charge on a capacitor
- ii. Electric schematic

e. Applications

- i. Automatic electric defibrillator
- ii. Flashbulbs in old cameras

f. Limits

- i. Irregularly-shaped capacitors

4. Model for Circuits and Resistance

a. Written Statements – Explanations and Predictions

- i. Resistance is the net effect of atomic level ‘obstacles’ interfering with the motion of charge carriers.
- ii. Resistance is directly proportional to resistivity of the material and length, and inversely proportional to cross-sectional area.
- iii. Resistance adds when resistors are connected in series; resistance reduces when resistors are connected in parallel.
- iv. A conducting path allows constrained charge motion between the points as an uneven charge distribution is maintained.
- v. When there is more than one pathway for current to travel, the total current into the junction is equal to the total current leaving the junction.
- vi. The voltage gains and drops around a closed loop of a circuit is equal to zero.
- vii. The equation relating current, voltage, and resistance is only valid for ohmic materials.
- viii. The rate at which charge accumulates on a capacitor or current flows in a RC circuit depends on the resistance and capacitance.
- ix. The electric potential of an inductor is the negative of the inductance and rate of change of current with respect to time.
- x. The rate of change of current in a RL circuit depends on the resistance and inductance.
- xi. An LC circuit acts as an oscillator, with energy transferring between the capacitor and inductor.

b. Equations

- i. $I = \frac{dQ}{dt}$
- ii. $I = \frac{\Delta V}{R}$
- iii. $P = I\Delta V$
- iv. $R = \frac{\rho l}{A}$
- v. $\vec{E} = \rho \vec{j}$
- vi. $I = Ne v_d A$
- vii. $R_s = \sum_i R_i$
- viii. $\frac{1}{R_p} = \sum_i \frac{1}{R_i}$
- ix. $I = I_0 e^{-t/RC}$
- x. $Q = CV \left(1 - e^{-t/RC}\right)$
- xi. $Q = Q_0 e^{-t/RC}$
- xii. $\mathcal{E} = -L \frac{dI}{dt}$
- xiii. $I = I_0 e^{-t/L/R}$
- xiv. $\omega = \sqrt{\frac{1}{LC}}$

- c. Graphs
 - i. Voltage versus current
 - ii. Resistance versus length
 - iii. Resistance versus cross-sectional area
 - iv. Current versus time
 - v. Charge versus time
- d. Diagram
 - i. Electric schematic
 - ii. Surface charge on a wire
- e. Applications
 - i. Power grids
 - ii. Analog electronics
- f. Limits
 - i. Non-ohmic materials
 - ii. Digital electronics

5. Model for Magnetic Field and Force

a. Written Statements – Explanations and Predictions

- i. Magnetic fields originate two locations: Permanent magnets and moving charges.
- ii. Field strength diminishes with distance from moving charge and increases with increasing charge motion.
- iii. Fields are loops and can be described with the right-hand rule.
- iv. Energy can be stored as a magnetic field in a solenoid.
- v. Inductance is a property of solenoids related to the geometry of the solenoid.
- vi. Force is exerted on a charge moving in a magnetic field.
- vii. Directions of force, charge/current, and magnetic field can be found with the right-hand rule.
- viii. The total force on a moving charged particle is the sum of the electric force and magnetic force.

b. Equations

- i. $\vec{B} = \frac{\mu_0 I}{2\pi r}$ [Long, straight wire]
- ii. $B_S = \mu_0 nI$
- iii. $U_L = \frac{1}{2} LI^2$
- iv. $\vec{F}_M = q\vec{v} \times \vec{B} = q|\vec{v}||\vec{B}| \sin \theta$
- v. $\vec{F}_M = I\vec{L} \times \vec{B} = I|\vec{L}||\vec{B}| \sin \theta$
- vi. $\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$

c. Graphs

- i. Magnetic field versus distance
- ii. Magnetic force versus velocity
- iii. Magnetic force versus magnetic field
- iv. Magnetic force versus angle

d. Diagrams

- i. Magnetic fields of permanent magnets
- ii. Magnetic fields of a long, straight current-carrying wire
- iii. Free-body diagram
- iv. Force diagram
- v. System interaction diagram

e. Applications

- i. Cyclotron
- ii. Solenoids

f. Limits

- i. Non-classical particles

6. Model for Electromagnetism

- a. Written Statements – Explanations and Predictions
 - i. Electric flux is the quantitative measure of the amount and direction of electric field over an entire surface.
 - ii. Gaussian surfaces can be used to determine values associated with electric fields and charge distributions.
 - iii. Magnetic flux is the quantitative measure of the amount and direction of magnetic field over an entire surface.
 - iv. Amperian loops can be used to determine values associated with magnetic fields and current distributions.
 - v. The closed-loop integral of the dot product between magnetic field and the area vector is equal to zero; this implies that a magnetic monopole cannot exist.
- b. Equation
 - i. $\Phi_E = \oint \vec{E} \cdot d\vec{A} = \frac{q}{\epsilon_0}$
 - ii. $\mathcal{E} = \oint \vec{E} \cdot d\vec{l}$
 - iii. $\Phi_B = \int \vec{B} \cdot d\vec{A}$
 - iv. $\mathcal{E} = -\frac{d\Phi_B}{dt}$
 - v. $\oint \vec{B} \cdot d\vec{l} = \mu_0 I$
 - vi. $\oint \vec{B} \cdot d\vec{A} = 0$
- c. Graphs
 - i. Electric flux versus position
 - ii. Magnetic flux versus position
 - iii. Magnetic flux versus time
- d. Diagrams
 - i. Electric flux diagram, with Gaussian surface
 - ii. Magnetic flux diagram, with Amperian loop
- e. Applications
 - i. Electromagnetic waves (light!)
 - ii. Electric motor
 - iii. Electric generator
- f. Limits
 - i. Non-classical particles

Section 6: Models for Mechanics

Note: I have listed at most two applications; however, models have many more than two applications.

1. Model for Constant Linear Velocity

- a. Written Statements – Explanations and Predictions
 - i. Path length is defined as the total distance traveled along a path from starting position to ending position.
 - ii. Displacement is defined as a change in the position state variable.
 - iii. Speed is defined as path length per change in time.
 - iv. Velocity is defined as a change in position per change in time.
 - v. The slope of position versus time graph is velocity.
 - vi. The area between function and time axis on velocity versus time graph is displacement.
- b. Equations
 - i. $\Delta\vec{x} = x_f - x_i$
 - ii. $\vec{v} = \frac{\Delta\vec{x}}{\Delta t}$
- c. Graphs
 - i. Position versus time
 - ii. Velocity versus time
- d. Diagram
 - i. Motion map
- e. Applications
 - i. Determining the “best” path when traveling
 - ii. Calculating calories burned during a workout
 - iii. Calculating the intersection point of two objects
- f. Limits
 - i. Non-constant linear velocity
 - ii. Changing the direction of the velocity

2. Model for Constant Angular Velocity

a. Written Statements – Explanations and Predictions

- i. Path length is defined as the total distance traveled along a path from starting position to ending position.
- ii. Angular displacement is defined as a change in the angle state variable.
- iii. Angular velocity is change in angle per change in time.
- iv. The slope of angle versus time graph is angular velocity.
- v. The area between function and time axis on angular velocity versus time graph is change in angular displacement.
- vi. The relationship between path length and angle is determined by the distance from the particle to the axis of rotation.
- vii. The relationship between tangential and angular velocities is determined by the distance from the particle to the axis of rotation.

b. Equations

- i. $\Delta\vec{\theta} = \theta_f - \theta_i$
- ii. $s = r\theta$
- iii. $v = r\omega$
- iv. $\vec{\omega} = \frac{\Delta\vec{\theta}}{\Delta t}$

c. Graph

- i. Angle versus time
- ii. Angular velocity versus time

d. Diagram

- i. Motion map

e. Applications

- i. Determining the “best” path around a curved surface
- ii. Determining the launch point of a projectile when swinging
- iii. Calculating the intersection point of two objects

f. Limits

- i. Non-constant angular velocity

3. Model for Uniform Linear Acceleration

- a. Written Statements – Explanations and Predictions
 - i. Acceleration is defined as a change in velocity per change in time.
 - ii. Slope of a velocity versus time graph is acceleration.
 - iii. Area between function and time axis on acceleration versus time graph is change in velocity.
- b. Equations
 - i. $\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$
 - ii. $v_x = v_{x0} + a_x t$
 - iii. $x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$
 - iv. $v_x^2 = v_{x0}^2 + 2a_x(x - x_0)$
- c. Graphs
 - i. Position versus time
 - ii. Position versus (time)²
 - iii. Velocity versus time
 - iv. Acceleration versus time
- d. Diagram
 - i. Motion map
- e. Applications
 - i. Calculating the stopping displacement when driving a car
 - ii. Determining the acceleration of a free-falling object
- f. Limits
 - i. Non-uniform linear acceleration

4. Model for Uniform Angular Acceleration

- a. Written Statements – Explanations and Predictions
 - i. Angular acceleration is defined as a change in angular velocity per change in time.
 - ii. The slope of an angular velocity versus time graph is angular acceleration.
 - iii. The area between function and time axis on angular acceleration versus time graph is change in angular velocity.
 - iv. The relationship between tangential and angular accelerations is determined by the distance from the particle to the axis of rotation.
- b. Equations
 - i. $a = r\alpha$
 - ii. $\vec{\alpha} = \frac{\Delta\vec{\omega}}{\Delta t}$
 - iii. $\omega = \omega_0 + \alpha t$
 - iv. $\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$
 - v. $\omega_x^2 = \omega_{x0}^2 + 2\alpha_x(\theta - \theta_0)$
- c. Graphs
 - i. Angle versus time
 - ii. Angle versus (time)²
 - iii. Angular velocity versus time
- d. Diagrams
 - i. Motion map
- e. Applications
 - i. Calculating the angular acceleration of a vinyl record
 - ii. Determining the angular acceleration of an object in a circle
- f. Limits
 - i. Non-uniform angular acceleration

5. Model for 2-D Motion

- a. Written Statements – Explanations and Predictions
 - i. A projectile moves horizontally and vertically and traces a parabolic path in the absence of air resistance.
 - ii. Horizontal and vertical motion of projectile are independent; time is the link between the two directions.
- b. Equations
 - i. $x = x_0 + v_{x0}t + \frac{1}{2}a_x t^2$
 - ii. $y = y_0 + v_{y0}t + \frac{1}{2}a_g t^2$
 - iii. $v_x^2 = v_{x0}^2 + 2a_x(x - x_0)$
 - iv. $v_y^2 = v_{y0}^2 + 2a_g(y - y_0)$
- c. Graphs
 - i. Position versus time
 - ii. Linear acceleration versus time
- d. Diagrams
 - i. Motion map
- e. Applications
 - i. Launching and landing projectiles
 - ii. Impact point of projectiles
- f. Limits
 - i. Non-zero forces in the horizontal direction
 - ii. More forces (besides F_g) in the vertical direction

6. Model for Linear Momentum

- a. Written Statements – Explanations and Predictions
 - i. Linear momentum is defined as the mass multiplied by velocity.
 - ii. The center of mass of an object is determined by amount and placement of mass.
 - iii. Depending on the system, linear momentum can either be conserved or not conserved.
- b. Equations
 - i. $\vec{p} = m\vec{v}$
 - ii. $\vec{p}_{1i} + \vec{p}_{2i} + \dots = \vec{p}_{1f} + \vec{p}_{2f} + \dots$
 - iii. $x_{CM} = \frac{\sum_i m_i x_i}{\sum_i m_i}$
- c. Graphs
 - i. Linear velocity versus time
- d. Diagrams
 - i. Motion map
 - ii. $p_i - \Delta p - p_f$ chart
- e. Applications
 - i. Determining the center of mass of non-standard objects
 - ii. Calculating the initial or final velocity of an object for various cases
- f. Limits
 - i. Non-constant velocity
 - ii. Non-constant mass

7. Model for Angular Momentum

a. Written Statements – Explanations and Predictions

- i. Angular momentum of a particle is determined by the cross product of the distance from the rotation point and linear momentum.
- ii. Angular momentum of an object is determined by the moment of inertia of the object and its angular velocity.
- iii. The moment of inertia of an object is found by summing the combination of each small part of mass and distance from the rotation point.
- iv. The Parallel Axis Theorem provides a method for calculating the moment of inertia for an object with a rotation point other than the center of mass.
- v. Depending on the system, angular momentum can either be conserved or not conserved.

b. Equations

- i. $\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$
- ii. $I = \int r^2 dm = \sum m r^2$
- iii. $I = I_{CM} + Md^2$
- iv. $\vec{L}_{1i} + \vec{L}_{2i} + \dots = \vec{L}_{1f} + \vec{L}_{2f} + \dots$

c. Graphs

- i. Angular momentum and linear momentum
- ii. Angular momentum and angular velocity

d. Diagrams

- i. Drawing of object
- ii. $L_i - \Delta L - L_f$ chart

e. Applications

- i. Determine the angular momentum of a satellite in orbit
- ii. Determine if angular momentum is conserved or non-conserved for a given system

f. Limits

- i. Non-constant linear momentum
- ii. Non-constant radius
- iii. Non-constant moment of inertia
- iv. Non-constant angular velocity

8. Model for Balanced Force

- a. Written Statements – Explanations and Predictions
 - i. Forces are interactions between two objects.
 - ii. Forces can be classified as either contact or non-contact.
 - iii. Objects acted upon by balanced forces will not accelerate; instead, they remain at rest or move with constant linear velocity.
 - iv. Forces are symmetric interactions (exist in pairs); paired forces are equal in magnitude but opposite in direction.
- b. Equation
 - i. $\sum \vec{F} = \vec{F}_{net} = 0$
- c. Diagrams
 - i. Force diagram
 - ii. Free-body diagram
 - iii. Interaction diagram
- d. Applications
 - i. Calculate the necessary force to keep an object in constant velocity
 - ii. Determine the placement of an object to keep a structure standing
- e. Limits
 - i. Unbalanced forces in any direction

9. Model for Unbalanced Force

a. Written Statements – Explanations and Predictions

- i. From changes in momentum, we infer forces.
- ii. From forces, we deduce changes in momentum.
- iii. Impulse is defined as the change in momentum or the integral of the force multiplied by time.
- iv. Acceleration is directly proportional to net force and inversely proportional to mass.
- v. The numerical value for coefficient of friction is determined by the surfaces.
- vi. Springs are an example of a restoring force; each spring has a spring constant.
- vii. The period of an object in circular motion is defined as the time needed to make one complete rotation.
- viii. As an object travels in a curved path, the direction of the velocity changes.
- ix. Acceleration (centripetal) from the velocity change in direction points toward the center of the circle.
- x. Force diagrams for an object undergoing circular motion show a net force directed toward the center of the circle.

b. Equations

- i. $\vec{F} = \frac{d\vec{p}}{dt}$
- ii. $\vec{J} = \int \vec{F} dt = \Delta\vec{p}$
- iii. $\vec{a} = \frac{\Sigma \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$
- iv. $|\vec{F}_f| \leq \mu |\vec{F}_N|$
- v. $\vec{F}_S = -k\Delta\vec{x}$
- vi. $a_c = \frac{v^2}{r} = \omega^2 r$
- vii. $F_c = \frac{mv^2}{r}$
- viii. $T = \frac{2\pi}{\omega} = \frac{1}{f}$

c. Graphs

- i. Impulse versus time
- ii. Force versus acceleration
- iii. Force of friction versus normal force
- iv. Spring force versus spring displacement

d. Diagrams

- i. Force diagram
- ii. Free-body diagram
- iii. Motion map
- iv. Interaction diagram

e. Applications

- i. Determine the forces experienced during a collision
- ii. Create a method for minimizing the forces experienced during a collision

f. Limits

- i. Objects moving at speeds near the speed of light
- ii. Extremely small or large objects

10. Model for Balanced Torque

- a. Written Statements – Explanations and Predictions
 - i. Torque is calculated by the cross product between the distance from a rotation point and the applied force.
 - ii. When the net torque at a rotation point equals zero, the object will remain at rest or move with constant angular velocity.
- b. Equations
 - i. $\vec{\tau} = \vec{r} \times \vec{F}$
 - ii. $|\vec{\tau}| = |\vec{r}||\vec{F}|\sin\theta$
 - iii. $\sum \vec{\tau} = \vec{\tau}_{net} = 0$
- c. Graphs
 - i. Torque versus force
- d. Diagrams
 - i. Force diagram
- e. Applications
 - i. Determine the amount of force it takes to rotate an object for different rotation points
 - ii. Calculate the amount of torque needed to ensure the object does not rotate
- f. Limits
 - i. Non-zero net torque

11. Model for Unbalanced Torque

- a. Written Statements – Explanations and Predictions
 - i. When a non-zero net torque is exerted on a rotation point, the object will undergo an angular acceleration.
 - ii. The net torque is equal to the product of the moment of inertia and angular acceleration.
- b. Equations
 - i. $\vec{\alpha} = \frac{\Sigma \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$
 - ii. $\vec{\tau} = \frac{d\vec{L}}{dt}$
- c. Graphs
 - i. Net torque versus angular acceleration
 - ii. Net torque versus time
- d. Diagrams
 - i. Force diagram
- e. Applications
 - i. Determine the torque necessary to start or stop a spinning object
 - ii. Calculate the torque needed to drive a screw into an object
- f. Limit
 - i. Non-uniform angular acceleration

12. Model for Energy, Work, and Power

- a. Written Statements – Explanations and Predictions
 - i. Energy is not disembodied; it is either stored in an object or by a field.
 - ii. Kinetic energy—either translational, rotational, or both—is the energy stored by a moving object.
 - iii. Elastic energy is stored in a deformable body.
 - iv. The magnitude of potential energy depends on the strength of the field and arrangement of objects in the field.
 - v. Thermal energy includes the kinetic energy associated with the random motion of particles and the potential energy associated with stretching, compressing, and bending the bonds among objects in a system.
 - vi. Energy can be transferred between a system and the surroundings by working, heating, or radiating.
 - vii. Power is the rate of energy transfer.
 - viii. Working relates the net or individual force with the displacement through an integration of the path length.
- b. Equations
 - i. $K = \frac{1}{2}mv^2$
 - ii. $\Delta U_g = mg\Delta h$
 - iii. $U_s = \frac{1}{2}k(\Delta x)^2$
 - iv. $K = \frac{1}{2}I\omega^2$
 - v. $\Delta E = W = \int \vec{F} \cdot d\vec{r}$
 - vi. $P = \frac{dE}{dt}$
 - vii. $P = \vec{F} \cdot \vec{v}$
- c. Graphs
 - i. Velocity versus time
 - ii. Energy versus position
 - iii. Force versus position
- d. Diagrams
 - i. Force diagram
 - ii. Free-body diagram
 - iii. Energy bar chart (LOL diagram)
- e. Applications
 - i. Rube Goldberg machine
 - ii. Motion of objects
- f. Limits
 - i. Energy of light

13. Model for Oscillations

- a. Written Statements – Explanations and Predictions
 - i. A plot of position versus time for ideal mass-spring or pendulum system follows repeating function (either sine or cosine).
 - ii. The period for a mass-spring system depends on mass and spring constant.
 - iii. The period for a pendulum depends on length and acceleration due to gravity.
- b. Equations
 - i. $T = \frac{2\pi}{\omega} = \frac{1}{f}$
 - ii. $x = A \cos(\omega t + \varphi)$
 - iii. $v = -\omega A \sin(\omega t + \varphi)$
 - iv. $a = -\omega^2 A \cos(\omega t + \varphi)$
 - v. $\frac{d^2x}{dt^2} = -Cx$
 - vi. $T_S = 2\pi \sqrt{\frac{m}{k}}$
 - vii. $T_p = 2\pi \sqrt{\frac{l}{g}}$
 - viii. $T_{\text{physical pendulum}} = 2\pi \sqrt{\frac{I}{mgx}}$
 - ix. $T_{\text{torsional pendulum}} = 2\pi \sqrt{\frac{I}{\kappa}}$
- c. Graphs
 - i. Position versus time
 - ii. Velocity versus time
 - iii. Acceleration versus time
- d. Diagrams
 - i. Motion map
 - ii. Force diagram
 - iii. Free-body diagram
 - iv. Energy bar chart (LOL diagram)
- e. Applications
 - i. Counter-balancing pendulum at the top of a skyscraper
 - ii. Windings in a clock
- f. Limits
 - i. Pendula released from greater than approximately 10 degrees
 - ii. Friction of components

14. Model for Gravitation

- a. Written Statements – Explanations and Predictions
 - i. The motion of an object in orbit does not depend on the object’s mass.
 - ii. The relationship the cube of the radius and square of the period is true for circular and elliptical orbits.
- b. Equations
 - i. $\left(\frac{4\pi^2}{GM}\right)r^3 = T^2$
 - ii. $|\vec{F}_G| = \frac{Gm_1m_2}{r^2}$
 - iii. $U_G = -\frac{Gm_1m_2}{r}$
- c. Graphs
 - i. Period versus radius
 - ii. Energy versus radius
- d. Diagrams
 - i. Force diagram
 - ii. Free-body diagram
 - iii. Energy bar chart (LOL diagram)
- e. Applications
 - i. Rocket launches
 - ii. Satellite orbits
- f. Limits
 - i. Systems where objects orbit each other

Section 7: Model for a Concept in AP Physics C

Written Statements – Explanations and Predictions	Equations
Graphs	Diagrams
Applications	Limits